ISSN 2250-3153

The Effect of Injection Pressure and Injection Timing on Performance and Emission Parameters with Algae Oil Methyl Ester Blend as a Fuel for CI Engine

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Abstract- It has become increasingly obvious that continued reliance on fossil fuel energy resources is unsustainable, owing to both depleting world reserves and the green house gas emissions associated with their use. Therefore, there are vigorous research initiatives aimed at developing alternative renewable and potentially carbon neutral Biofuels as alternative energy resources. Algae as a feedstock is emerging at the forefront of biofuel research due to increasing awareness of global energy issues in conjunction with the production limitations of agriculture-based oilseed crops. The present paper is focused on experimentally investigating the influence of injection pressure and injection timing on brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), unburned hydrocarbon (UBHC), carbon monoxide (CO), oxides of nitrogen (NOx) and smoke opacity of a single cylinder compression ignition engine when blends (20%) of algal oil methyl ester are used as a fuel. Engine performance test show that algae oil as a fuel does not differ greatly from that of diesel. The results showed a better performance and reduced emissions at an injection pressure of 200bar.

***Index terms*:** Algae, biofuel, injection pressure, injection timing

I. Introduction

Fuel is an indicator of today’s progress of scientific era. The economic progress of a country will be decided by the amount of fuel consumption per capita. India is home to more than billion people, about “one sixth” of the world human population. One factor that has decelerated India’s rate of economic development is the need to import of about 70% of petroleum demand which costs approximately Rs.879000 corers per annum. Import of petroleum products is a major drain on our foreign exchange resources and with growing demand in future years, the situation is likely to become even worse. Hence it has become imperative to find alternative fuels which can be produced in our own country [1]. The diesel engine has gained the name and fame by serving the society in many ways viz. transportation, Industrial and agricultural sectors. Hence Diesel fuel is the single largest source to power vehicles. Its main attractions are ruggedness in construction, simplicity in operation and ease of maintenance. With increasing demand on the use of petroleum products, a stronger threat to clean environment is being poised as the burning of these fuels is associated with emissions like CO_2, CO, NO_x and particulate matter, which is currently the dominant global source of emissions. These emissions are major causes of air pollution and hence the environment. The most appealing alternative fuels are those, which can be used with minimum or without modifications of existing engines [2].

II. BIODIESEL PRODUCTION

Biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats which conform to ASTM D6751 specifications for use in diesel engines. Biodiesel molecules are mixture of fatty acids methyl esters (FAMEs) produced usually from transesterification reaction between triglycerides esters (vegetable oil or animal fat) and alcohol (methanol) in presence of alkalis such as potassium hydroxide or sodium hydroxide as catalyst.

Transesterification of algae oil

Biodiesel production from microalgae can be done using several well known industrial processes, the most common of which is base catalyzed transesterification with alcohol. The transesterification is the reversible reaction of fat or oil (which is composed of triglyceride) with an alcohol to form fatty acid alkyl ester and glycerol. Stoichio-metrically, the reaction requires a 3:1 molar alcohol to oil ratio, but excess alcohol is (usually methyl alcohol is used) added to drive the equilibrium toward the product side [3]. This large excess of methyl alcohol ensures that the reaction is driven in the direction of methyl esters, i.e. towards biodiesel. Yield of methylesters exceeds 98% on a weight basis [4]. The reaction occurs stepwise: triglycerides are first converted to diglycerides, then to monoglycerides and finally to glycerol [5]. Transesterification can be done in number of ways such as using an alkali catalyst, acid catalyst, enzyme catalyst, heterogeneous catalyst or using alcohol in their supercritical state; however enzyme catalyst are rarely used as they are less effective [6]. The alkali-catalyzed transesterification is about 4000 times faster than the acid catalyzed reaction. Consequently, alkalis such as sodium and potassium hydroxide are commonly used as commercial catalysts at a concentration of about 1% by weight of oil. Alkoxides such as sodium methoxide are even better catalysts than sodium hydroxide and are being increasingly used. Use of lipases offers important advantages [7].

II. PROPERTIES OF ALGAE OIL

The physical and chemical property of algal oil methyl ester was found satisfactory against ASTM standards. The density and specific gravity of AOME and diesel used in study is found at 40^0C which lied close to each other against the ASTM standards.

ISSN 2250-3153

The flash point of AOME is found to be 145^{0}C which lies within the ASTM biodiesel standards. The kinematic viscosity at 40^{0}C for AOME was found to be 5.76 mm^{2}s-1. AOME was found to have slight higher water content than ASTM biodiesel standards. The Cetane was found to be increasing with an increase in AOME in diesel while the calorific value of AOME was found to be decreasing with the addition of AOME. Heat of combustion for straight diesel is 42000kJ/kg while AOME 20% has 40920kJ/kg which is lesser. The flash point and boiling point also exhibits a decreasing trend with an increase in AOME blends.

Table 1: Properties of AOME in comparison with ASTM D6751 (Biodiesel)

Sl. No.	Property	Unit	AOME	ASTM D6751 Biodiesel
1	Density at 40^{0}C	g cm$_{-3}$	0.8712	0.86-0.90
2	Specific Gravity at 40^{0}C	g cm$_{-3}$	0.894	0.88
3	Flash point	^{0}C	145	100-170
4	Kinematic Viscosity at 40^{0}C	mm^2 s$_{-1}$	5.76	1.9-6.0
5	Water Content	%	0.04	<0.03
6	Ash Content	%	0.02	<0.02
7	Carbon Residue	%	0.03	-
8	Acid Value	mg KOH g$_{-1}$	0.34	0.5
9	Sulphur content	%	0.042	0.05

Table 2: Properties of Algal oil methyl ester blend with Straight Diesel

Sl. No.	Fuel/Property	Cetane No.	Boiling Point (^{0}C)	Flash point (^{0}C)	Heat of combustion (k J/ kg)
1	Straight Diesel	45	317	60	42000
2	AOME 10% - Diesel Blend	47	261	61	41005
3	AOME 20% - Diesel Blend	47	254	60	40920
4	AOME 30% - Diesel Blend	48	247	59	40830

III. EXPERIMENTATION

The experimental work carried out for the objectives, requires an engine test set-up adequately instrumented for acquiring necessary performance. Algae oil methyl ester blends (20%) and pure Diesel were used to test a TV1, Kirloskar, single cylinder, 4-stroke, water-cooled diesel engine having a rated output of 5.2 kW at 1500 rpm and a compression ratio of 17.5:1 under variable injection pressure and injection timing. The engine was coupled with an eddy current dynamometer to apply different engine loads. The experimental set-up and photographic views of engine are as shown in Figure 1 and 2. The test bed is fully instrumented to measure the various parameters such as flow measurement, load measurement, pressure measurement, etc during the experiments on the engine.

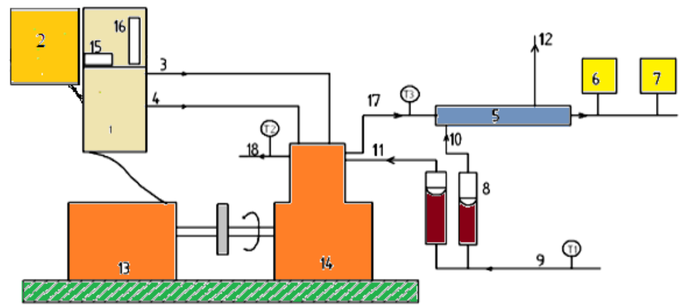

Fig. 1: Schematic diagram of the experimental set up

Fig.2: photographic view of Diesel engine test rig

1 -Control Panel , 2 -Computer system, 3 -Diesel flow line,
4 - Air flow line, 5 –Calorimeter, 6-Exhaust gas analyzer,
7 -Smoke meter, 8 - Rota meter, 9-Inlet water temperature,
10- Calorimeter inlet water temp, 11-Inlet water temperature,
12 -Calorimeter outlet water temp, 13-Dynamometer,
14-CI Engine, 15 - Speed measurement,
16-Burette for fuel measurement, 17 -Exhaust gas outlet,
18-Outlet water from engine, T_1- Inlet water temperature,
T_2-Outlet water temperature, T_3- Exhaust gas temperature.

IV. RESULTS AND DISCUSSION

A. Effect of Injection Pressure on Engine Performance

i. Brake thermal efficiency (BTE): Fig. 3 shows the variation of brake thermal efficiency for compression ratio of 17.5 with brake mean effective pressure (BMEP) at injection pressure of 180 bar 200 bar and 220 bar for methyl esters of algae oil. Brake thermal efficiency is increased with increase in BMEP due to reduced heat loss with increase in power and increase in load.

The efficiency of all fuels is low at lower injection pressure; this is due to poor atomization and mixture formation of vegetable oils during injection. With increase in injection pressure, the brake thermal efficiency (BTE) is increased due to the reduction in the viscosity, improved atomization and better combustion. The maximum efficiency for all fuels tested is obtained at 200 bar injection pressure, this is due to fine spry formed during injection and improved atomization, which reduces the physical delay period resulting in better combustion and also observed that, the efficiency is again decreased at 220 bar, this may be due to that at higher injection pressure the size of fuel droplets decreases and very high fine fuel spray will be injected, because of this, penetration of fuel spray reduces and momentum of fuel droplets will be reduced [8].

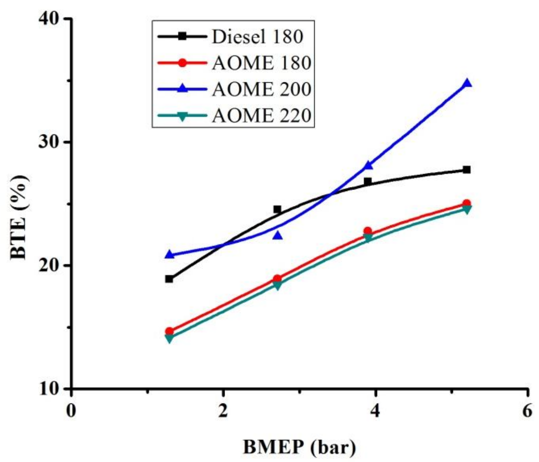

Fig. 3: Variation of BTE with BMEP at IT 27^0 Btdc

ii. Brake specific fuel consumption (BSFC): Fig. 4 shows the variation of BSFC with BMEP at injection pressure of 180 bar 200 bar and 220 bar for methyl esters of algae oil. The Figure shows that the BSFC for all fuels is higher than diesel fuel, which was observed due to lower calorific value of bio diesel. It is found that the BSFC is decreased with increase in injection pressure to 200 bar. This may be due to the fact that, as injection pressure increases the penetration length and spray cone angle increases, so that at optimum pressure, fuel air mixing and spray atomization will be improved [9].

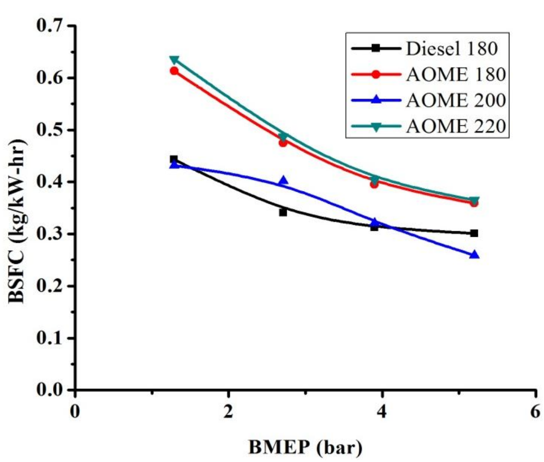

Fig. 4: Variation o fBSFC with BMEP at IT 27^0 Btdc

B. Effect of Injection Pressure on Engine Emissions

i. Unburnt hydrocarbons (UBHC): Fig. 5 shows the variation of UBHC with BMEP. The UBHC is increased with increase in BMEP for all fuels. It is observed that the UBHC emissions for all bio diesels are lower than the diesel fuel, indicating that the heavier hydrocarbon particles that are present in the diesel fuel increase UBHC emissions. The UBHC emission of methyl esters at full load is approximately 31 to 34% lower than the diesel value[9].

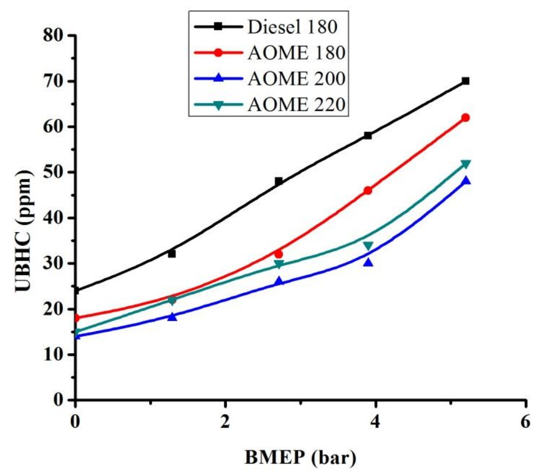

Fig. 5: Variation of UBHC with BMEP at IT 27^0 bTDC

ii. Carbon monoxide (CO): Variation of carbon monoxide (CO) with BMEP is shown in Figures 6. Carbon monoxide emissions from a diesel engine mainly depend upon the physical and chemical properties of the fuel. The bio diesel itself contains 11% of oxygen which helps for complete combustion. It is found that the amount of CO is decreased at part loads and again increased at full load condition for all fuels. This is common in all internal combustion engines since air-fuel ratio decreases with increase in load. The carbon monoxide emissions increase as the fuel air ratio becomes grater. The CO emission for fuels used at full BMEP is approximately 40 to 45% lower than the corresponding value for diesel[10].

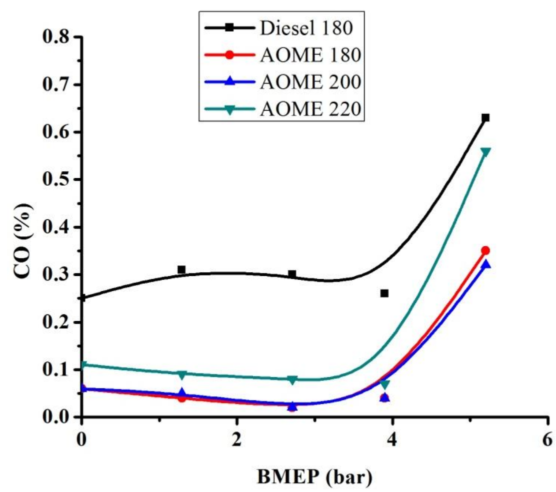

Fig. 6: Variation of CO with BMEP at IT 27^0 Btdc

ii. Oxides of Nitrogen (NO_x): Variation of NO_x with BMEP is shown in Fig. 7. The nitrogen oxides results from the oxidation of atmospheric nitrogen at high temperature inside the combustion chamber of an engine rather than resulting from a contaminant present in the fuel. Although nitrogen oxides are considered as major contributor for ozone formation and also reality of operating internal combustion engines. From the Fig. it is seen that the amount of NO_x is increased with increase in BMEP for all fuels this is because with increasing load, the temperature of combustion chamber increases and NO_x formation is a strongly temperature dependent phenomenon and is that the average NOx emission in the case of conditioned bio diesel is slightly higher than the diesel fuel. These higher NO_x emissions due to higher temperature of combustion chamber using conditioned bio diesel[12]. NO_x emissions were lower at 200 bar injection pressure indicating that effective combustion was taking place during the early part of expansion stroke.

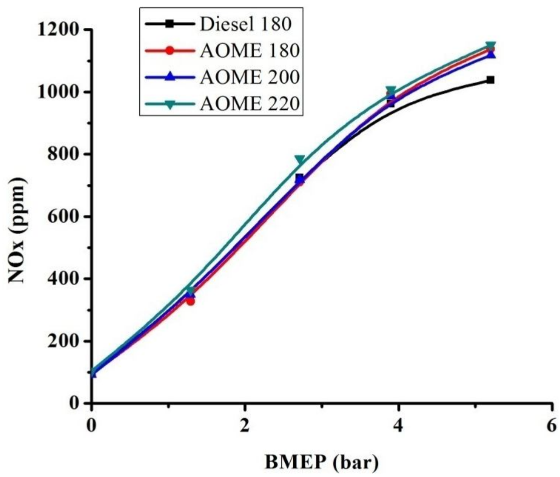

Fig. 7: Variation of NO_x with BMEP at IT 27^0 Btdc

iv. Smoke opacity: Fig. 8 indicates the variation of smoke opacity with BMEP. It is found that the opacity is increased with increase in load. It also shows that the opacity variation is lower for conditioned bio diesel compared to diesel fuel[13]. The average opacity at full load for methyl esters is 64% which is almost same when compared to that of diesel fuel.

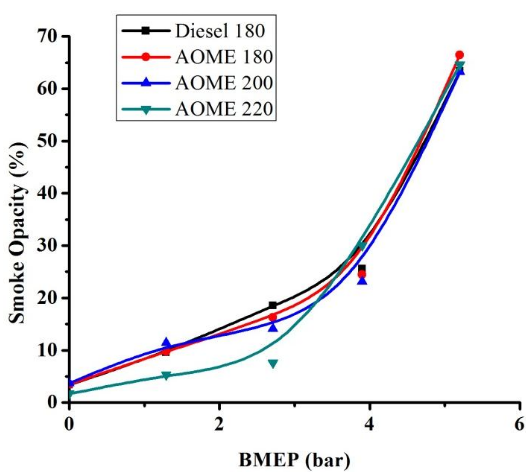

Fig. 8: Variation of Smoke opacity with BMEP at IT 27^0 Btdc

C. Effect of Injection Timing on Engine Performance at Optimized Injection Pressure of 200bar

i. Brake thermal efficiency (BTE): Fig.9 show the variation of brake thermal efficiency (BTE) with BMEP at various injection timing for methyl esters of algae oil. For all fuels, the BTE is improved with increase in BMEP. Brake thermal efficiency increases when the injection timing is advanced. This is because starting the combustion earlier compensates the effect of slow burning. Combustion is slow with conditioned bio diesel on account of its high viscosity which leads to a poor spray and mixture with air[13]. The maximum brake thermal efficiency occurred at the static injection timing of 30^0 bTDC which is selected as optimal. This is 3^0 more advanced than that of diesel.

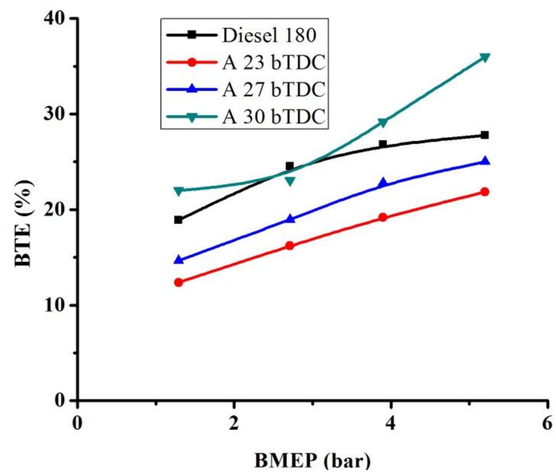

Fig. 9: Variation of BTE with BMEP at 200bar injection Pressure

ii. Brake specific fuel consumption (BSFC): Fig. 10 shows the variation of BSFC with BMEP at injection pressure of 180 bar 200 bar and 220 bar for methyl esters of algae oil. BMEP of a diesel engine directly relates to the brake power. It can also observed that advance of injection timing leads with lower BSFC this is due to optimum delay period and smaller amount of fuel during after burning[14].

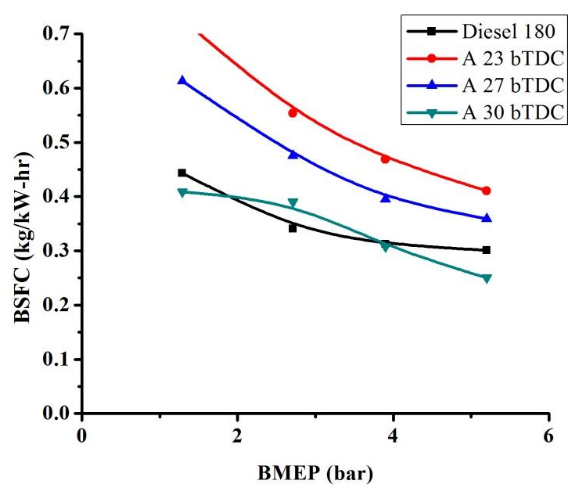

Fig. 10: Variation of BSFC with BMEP at 200bar injection Pressure

D. Effect of Injection Timing on Engine Emissions at Optimized Injection Pressure of 200bar

i. Unburnt hydrocarbons (UBHC): Fig. 11 shows the variation of UBHC with BMEP. The UBHC is increased with increase in BMEP for all fuels. The UBHC emissions for all conditioned bio diesel are lower than the diesel fuel by 34%. HC emission is lowest with the injection timing namely 30^0 bTDC is shown in Fig 11. This injection timing lowers the HC level at all loads due to improved combustion and use of over leaner fuel air mixtures as compared to other timings 23^0bTDC and 27^0bTDC and account improved brake thermal efficiency. The HC level at full load falls off from average 66 ppm with the timing of 23^0bTDC to average 46 ppm with the best injection timing of average 30^0bTDC.

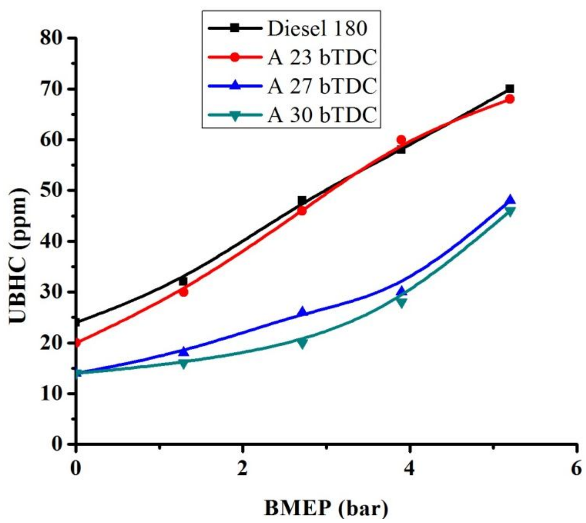

Fig. 11: Variation of UBHC emission with BMEP at 200bar IP

ii. Carbon monoxide (CO): Fig. 12 represents variation of CO emissions with BMEP. An increase in BMEP at any conditioned oil and injection timing at low load CO level increases and medium loads CO level decreases slightly. At all loads, at 30^obTDC injection timing condition of CO level is less about 10**%** volume compared with 23^obTDC and 27^obTDC. This is because of optimum delay period. At 23^obTDC and 27^obTDC injection timing, the timing required for proper mixing of air and conditioned bio diesel may not be sufficient, this will result high fuel consumption and exhaust level[15].

iii. Oxides of Nitrogen (NO_x): Variation of NO_x with BMEP is shown in Fig.13. it can observed that the NO_x emission level increases with advance the injection timing as expected due to increased cylinder gas temperatures[16]. At full load the average increase of 1130 ppm at the injection timing of 23^0bTDC to 1160 ppm with the optimum timing of 30^0bTDC with conditioned bio diesel.

iv. Smoke opacity: Fig. 14 indicates the variation of smoke opacity with BMEP. The opacity is increased with increase in load. The Fig. shows that the opacity is in significant variation with conditioned bio diesel compared to diesel fuel. The smoke level decreases as the injection timing is advanced, as is normal in diesel engines because of the dominance of the premixed combustion phase[17].

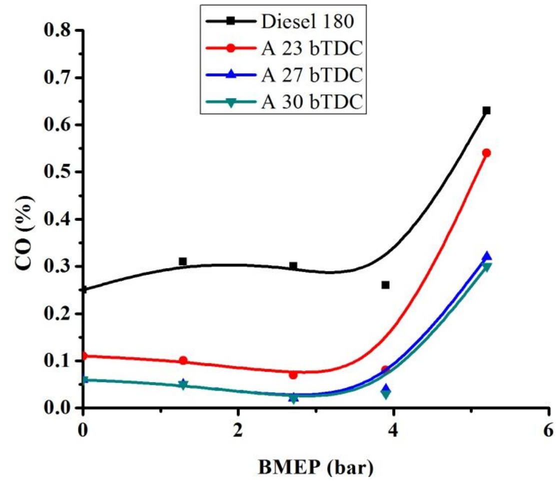

Fig. 12: Variation of CO emission with BMEP at 200bar IP

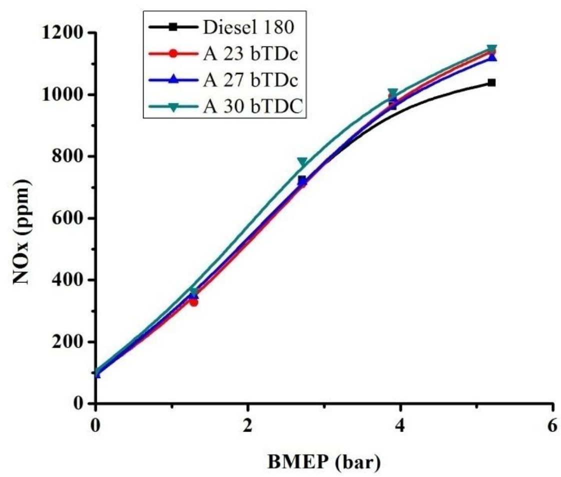

Fig. 13: Variation of NO_x emission with BMEP at 200bar IP

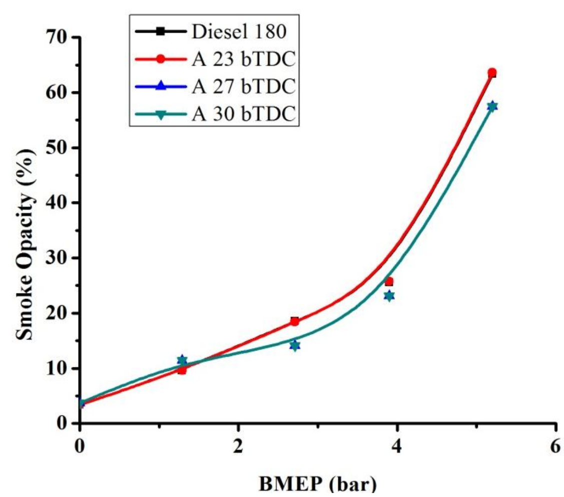

Fig. 14: Variation of Smoke opacity with BMEP at 200bar IP

VI. CONCLUSION

From the present experimental results and discussions it can be concluded that by increasing the injector opening pressure from the rated value for diesel (180bar) to 200 bar shows significant improvement in performance and emissions with algae oil methyl esters due to better spry formation. The injector opening pressure 220bar performance and emissions inferior than injector opening pressure 200 bar, this is due to that at higher pressure, the size of fuel droplets decreases and very high fine fuel spray will be injected, because of this, penetration of fuel spray reduces and momentum of fuel droplets will be reduced. Advancing the injection timing by 3^0 crank angle (i.e. 30^0bTDC) performance and emission characteristics have been improved significantly.

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